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HIGH DENSITY INTEGRATED CIRCUIT APPARATUS, TEST PROBE AND METHODS OF USE THEREOF

FIELD OF THE INVENTION

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This invention relates to an apparatus and test probe for integrated circuit devices and methods of use thereof.

BACKGROUND OF THE INVENTION

In the microelectronics industry, before integrated circuit (IC) chips are packaged in an electronic component, such as a computer, they are tested. Testing is essential to determine whether the integrated circuit's electrical characteristics conform to the specifications to which they were designed to ensure that electronic component performs the function for which it was designed.

Testing is an expensive part of the fabrication process of contemporary computing systems. The functionality of every I/O for contemporary integrated circuit must be tested since a failure to achieve the design specification at a single I/O can render an integrated circuit unusable for a specific application. The testing is commonly done both at room temperature and at elevated temperatures to test

functionality and at elevated temperatures with forced voltages and currents to burn the chips in and to test the reliability of the integrated circuit to screen out early failures.

Contemporary probes for integrated circuits are expensive to fabricate and are easily damaged. Contemporary test probes are typically fabricated on a support substrate from groups of elongated metal conductors which fan inwardly towards a central location where each conductor has an end which corresponds to a contact location on the integrated circuit chip to be tested. The metal conductors generally cantilever over an aperture in the support substrate. The wires are generally fragile and easily damage and are easily displaceable from the predetermined positions corresponding to the design positions of the contact locations on the integrated circuit being tested. These probes last only a certain number of testing operations, after which they must be replaced by an expensive replacement or reworked to recondition the probes.

Figure 1 shows a side cross-sectional view of a prior art probe assembly 2 for probing integrated circuit chip 4 which is disposed on surface 6 of support member 8 for integrated circuit chip 4. Probe assembly 2 consists of a dielectric substrate 10 having a central aperture 12 therethrough. On surface 14 of substrate 10 there are disposed a plurality of electrically conducting beams which extend towards edge 18 of aperture 12. Conductors 16 have ends 20 which bend downwardly in a direction generally perpendicular to the plane of surface 14 of substrate 10. Tips 22 of downwardly projecting electrically conducting ends 20 are disposed in electrical contact with contact locations 24 on surface 25 of integrated circuit chip 4. Coaxial cables 26 bring electrical signals, power and ground through electrical connectors 28 at periphery 30 of substrate 10. Structure 2 of Figure 1 has the disadvantage of being expensive to fabricate and of having fragile inner ends 20 of electrical conductors 16. Ends 20 are easily damaged through use in probing electronic devices. Since the probe 2 is expensive to

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fabricate, replacement adds a substantial cost to the testing of integrated circuit devices. Conductors 16 were generally made of a high strength metal such as tungsten to resist damage from use. Tungsten has an undesirably high resistivity.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an improved high density test probe, test apparatus and method of use thereof.

It is another object of the present invention to provide an improved test probe for testing and burning-in integrated circuits.

It is another object of the present invention to provide an improved test probe and apparatus for testing integrated circuits in wafer form and as discrete integrated circuit chips.

It is an additional object of the present invention to provide probes having contacts which can be designed for high performance functional testing and for high temperature burn in applications.

It is yet another object of the present invention to provide probes having contacts which can be reworked several times by resurfacing some of the materials used to fabricate the probe of the present invention.

It is a further object of the present invention to provide an improved test probe having a probe tip member containing a plurality of elongated conductors each ball bonded to electrical contact locations on space transformation substrate.

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A broad aspect of the present invention is a test probe having a plurality of electrically conducting elongated members embedded in a material. One end of each conductor is arranged for alignment with contact locations on a workpiece to be tested.

In a more particular aspect of the present invention, the other end of the elongated conductors are electrically connected to contact locations on the surface of a fan-out substrate. The fan-out substrate provides space transformation of the closely spaced electrical contacts on the first side of the fan-out substrate. Contact locations having a larger spacing are on a second side of the fan out substrate.

In yet another more particular aspect of the present invention, pins are electrically connected to the contact locations on the second surface of the fan out substrate.

In another more particular aspect of the present invention, the plurality of pins on the second surface of the fan-out substrate are inserted into a socket on a second fan-out substrate. The first and second space transformation substrates provide fan out from the fine pitch of the integrated circuit I/O to a larger pitch of electrical contacts for providing signal, power and ground to the workpiece to be tested.

In another more particular aspect of the present invention, the pin and socket assembly is replaced by an interposer containing a plurality of elongated electrical connectors embedded in a layer of material which is squeezed between contact locations on the first fan- out substrate and contact locations on the second fan-out substrate.

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In another more particular aspect of the present invention, the test probe is part of a test apparatus and test tool.

Another broad aspect of the present invention is a method of fabricating the probe tip of the probe according to the present invention wherein a plurality of elongated conductors are bonded to contact locations on a substrate surface and project away therefrom.

In a more particular aspect of the method according to the present invention, the elongated conductors are wire bonded to contact locations on the substrate surface. The wires project preferably at a nonorthogonal angle from the contact locations.

In another more particular aspect of the method of the present invention, the wires are bonded to the contact locations on the substrate are embedded in a elastomeric material to form a probe tip for the structure of the present invention.

In another more particular aspect of the present invention, the elongated conductors are embedded in an elastomeric material.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic cross-section of a conventional test probe for an integrated circuit device.

Figure 2 is a schematic diagram of one embodiment of the probe structure of the present invention.

Figure 3 is a schematic diagram of another embodiment of the probe structure of the present invention.

Figure 4 is an enlarged view of an elastomeric connector electrically interconnecting two space transformation substrates of the structure of Figure 2.

Figure 5 is an enlarged view of the probe tip within dashed circle 100 of Figures 2 or 3.

Figure 6 shows the probe tip of the structure of Figure 5 probing an integrated circuit device.

Figures 7-13 show the process for making the structure of Figure 5.

Figure 14 shows a probe tip structure without a fan-out substrate.

Figure 15 shows the elongated conductors of the probe tip fixed by solder protuberances to contact locations on a space transformation substrate.

Figure 16 shows the elongated conductors of the probe tip fixed by laser weld protuberances to contact locations on a space transformation substrate.

Figure 17 shows both interposer 76 and probe tip 40 rigidly bonded to space transformer 60.

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DETAILED DESCRIPTION

Turning now to the figures, Figures 2 and 3 show two embodiments of the test assembly according to the present invention. Numerals common between Figures 2 and 3 represent the same thing. Probe head 40 is formed from a plurality of elongated electrically conducting members 42 embedded in a material 44 which is preferably an elastomeric material 44. The elongated conducting members 42 have ends 46 for probing contact locations on integrated circuit devices 48 of wafer 50. In the preferred embodiment, the workpiece is an integrated circuit such as a semiconductor chip or a semiconductor wafer having a plurality of chips. The workpiece can be any other electronic device. The opposite ends 52 of elongated electrical conductors 42 are in electrical contact with space transformer (or fan-out substrate) 54. In the preferred embodiment, space transformer 54 is a multilevel metal/ceramic substrate, a multilevel metal/polymer substrate or a printed circuit board which are typically used as packaging substrates for integrated circuit chips. Space transformer 54 has, in the preferred embodiment, a surface layer 56 comprising a plurality of thin dielectric films, preferably polymer films such as polyimide, and a plurality of layers of electrical conductors, for example, copper conductors. A process for fabricating multilayer structure 56 for disposing it on surface 58 of substrate 60 to form a space transformer 54 is described in US patent application Serial No. 07/695,368, filed on May 3, 1991, entitled "MULTI-LAYER THIN FILM STRUCTURE AND PARALLEL PROCESSING METHOD FOR FABRICATING SAME" which is assigned to the assignee of the present invention, the teaching of which is incorporated herein by reference. Details of the fabrication of probe head 40 and of the assembly of probe head 40 and 54 will be described herein below.

As sown in Figure 2, on surface 62 of substrate 60, there are, a plurality of pins 64. Surface 62 is opposite the surface 57 on which probe head 40 is disposed.

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Pins 64 are standard pins used on integrated circuit chip packaging substrates. Pins 64 are inserted into socket 66 or plated through-holes in the substrate 68 which is disposed on surface 70 of second space transformer 68. Socket 66 is a type of pin grid array (PGA) socket such as commonly disposed on a printed circuit board of an electronic computer for receiving pins from a packaging substrate. Second space transformer 68 can be any second level integrated circuit packaging substrate, for example, a standard printed circuit board. Socket 66 is disposed on surface 70 of substrate 68. On opposite surface 70 of substrate 68 there are disposed a plurality of electrical connectors to which coaxial cables 72 are electrically connected. Alternatively, socket 68 can be a zero insertion force (ZIF) connector or the socket 68 can be replaced by through-holes in the substrate 68 wherein the through-holes have electrically conductive material surrounding the sidewalls such as a plated through-hole.

In the embodiment of Figure 3, the pin 64 and socket 66 combination of the embodiment of Figure 2 is replaced by an interposer, such as, elastomeric connector 76. The structure of elastomeric connector 76 and the process for fabricating elastomeric connector 76 is described in copending US patent application Serial No. 07/963,364 to B. Beaman et al., filed October 19, 1992, entitled "THREE DIMENSIONAL HIGH PERFORMANCE INTERCONNECTION MEANS", which is assigned to the assignee of the present invention, the teaching of which is incorporated herein by reference and of which the present application is a continuation-in-part thereof, the priority date of the filing thereof being claimed herein. The elastomeric connector can be opted to have one end permanently bonded to the substrate, thus forming a FRU (field replacement unit) together with the probe/substrate/connector assembly.

Figure 4 shows a cross-sectional view of structure of the elastomeric connector 76 of Figure 3. Connector 76 is fabricated of preferably elastomeric material 78 having opposing, substantially parallel and planar surfaces 80 and 82. Through

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elastomeric material 78, extending from surface 81 to 83 there are a plurality of elongated electrical conductors 85. Elongated electrical conductors 84 are preferably at a nonorthogonal angle to surfaces 81 and 83. Elongated conductors 85 are preferably wires which have protuberances 86 at surface 81 of elastomeric material layer 78 and flattened protuberances 88 at surface 83 of elastomeric material layer 78. Flattened protuberances 88 preferably have a projection on the flattened surface as shown for the structure of Figure 14. Protuberance 86 is preferably spherical and flattened protuberance 88 is preferably a flattened sphere. Connector 76 is squeezed between surface 62 of substrate 54 and surface 73 of substrate 68 to provide electrical connection between end 88 of wires 85 and contact location 75 on surface 73 of substrate 68 and between end 88 or wires 85 and contact location 64 on surface 62 of substrate 54.

Alternatively, as shown in Figure 17, connector 76 can be rigidly attached to substrate 54 by solder bonding ends 88 of wires 85 to pads 64 on substrate 54 or by wire bonding ends 86 of wires 85 to pads 64 on substrate 54 in the same manner that wires 42 are bonded to pads 106 as described herein below with respect to Figure 5. Wires 85 can be encased in an elastomeric material in the same manner as wires 42 of Figure 5.

Space transformer 54 is held in place with respect to second space transformer 68 by clamping arrangement 80 which is comprised of member 82 which is perpendicularly disposed with respect to surface 70 of second space transformer 68 and member 84 which is preferably parallely disposed with respect to surface 86 of first space transformer 54. Member 84 presses against surface 87 of space transformer 54 to hold space transformer 54 in place with respect surface 70 of space transformer 64. Member 82 of clamping arrangement 80 can be held in place with respect to surface 70 by a screw which is inserted through member 84 at location 90 extending through the center of member 82 and screw into surface 70.

The entire assembly of second space transformer 68 and first space transformer with probe head 40 is held in place with respect wafer 50 by assembly holder 94 which is part of an integrated circuit test tool or apparatus. Members 82, 84 and 90 can be made from materials such as aluminum.

Figure 5 is a enlarged view of the region of Figures 2 or 3 closed in dashed circle 100 which shows the attachment of probe head 40 to substrate 60 of space transformer 54. In the preferred embodiment, elongated conductors 42 are preferably wires which are at a non-orthogonal angle with respect to surface 87 of substrate 60. At end 102 of wire 42 there is preferably a flattened protuberance 104 which is bonded (by wire bonding, solder bonding or any other known bonding technique) to electrically conducting pad 106 on surface 87 of substrate 60. Elastomeric material 44 is substantially flush against surface 87. At substantially oppositely disposed planar surface 108 elongated electrically conducting members 42 have an end 110. In the vicinity of end 110, there is optimally a cavity 112 surrounding end 110. The cavity is at surface 108 in the elastomeric material 44.

Figure 6 shows the structure of Figure 5 used to probe integrated circuit chip 114 which has a plurality of contact locations 116 shown as spheres such as a C4 solder balls. The ends 110 of conductors 42 are pressed in contact with contact locations 116 for the purpose of electrically probing integrated circuit 114. Cavity 112 provides an opening in elastomeric material 44 to permit ends 110 to be pressed towards and into solder mounds 116. Cavity 112 provides a means for solder mounds 116 to self align to ends 110 and provides a means containing solder mounds which may melt, seep or be less viscous when the probe is operated at an elevated temperature. When the probe is used to test or burn-in

workpieces have flat pads as contact locations the cavities 112 can remain or be eliminated.

Figures 7-13 show the process for fabricating the structure of Figure 5. Substrate 60 with contact locations 106 thereon is disposed in a wire bond tool. The top surface 122 of pad 106 is coated by a method such as evaporation, sputtering or plating with soft gold or Ni/Au to provide a suitable surface for thermosonic ball bonding. Other bonding techniques can be used such as thermal compression bonding, ultrasonic bonding, laser bonding and the like. A commonly used automatic wire bonder is modified to ball bond gold, gold alloy, copper, copper alloy, aluminum, Pt, nickel or palladium wires 120 to the pad 106 on surface 122 as shown in Figure 7. The wire preferably has a diameter of 0.001 to 0.005 inches. If a metal other than Au is used, a thin passivation metal such as Au, Cr, Co, Ni or Pd can be coated over the wire by means of electroplating, or electroless plating, sputtering, e-beam evaporation or any other coating techniques known in the industry. Structure 124 of Figure 7 is the ball bonding head which has a wire 126 being fed from a reservoir of wire as in a conventional wire bonding apparatus. Figure 7 shows the ball bond head 124 in contact at location 126 with surface 122 of pad 106.

Figure 8 shows the ball bonding head 124 withdrawn in the direction indicated by arrow 128 from the pad 106 and the wire 126 drawn out to leave disposed on the pad 106 surface 122 wire 130. In the preferred embodiment, the bond head 124 is stationary and the substrate 60 is advanced as indicated by arrow 132. The bond wire is positioned at an angle preferably between 5 to 60° from vertical and then mechanically notched (or nicked) by knife edge 134 as shown in Figure 9. The knife edge 134 is actuated, the wire 126 is clamped and the bond head 124 is raised. The wire is pulled up and breaks at the notch or nick.

Cutting the wire 130 while it is suspended is not done in conventional wire bonding. In conventional wire bonding, such as that used to fabricate the electrical connector of US Patent 4,998,885, where, as shown in Figure 8 thereof, one end a wire is ball bonded using a wire bonded to a contact location on a substrate bent over a loop post and the other of the wire is wedge bonded to an adjacent contact location on the substrate. The loop is severed by a laser as shown in Figure 6 and the ends melted to form balls. This process results in adjacent contact locations having different types of bonds, one a ball bond the other a wedge bond. The spacing of the adjacent pads cannot be less than about ~ 20 mils because of the need to bond the wire. This spacing is unacceptable to fabricate a high density probe tip since dense integrated circuits have pad spacing less than this amount. In contradistinction, according to the present invention, each wire is ball bonded to adjacent contact locations which can be spaced less than 5 mils apart. The wire is held tight and knife edge 134 notches the wire leaving upstanding or flying leads 120 bonded to contact locations 106 in a dense array.

When the wire 130 is severed there is left on the surface 122 of pad 106 an angled flying lead 120 which is bonded to surface 122 at one end and the other end projects outwardly away from the surface. A ball can be formed on the end of the wire 130 which is not bonded to surface 122 using a laser or electrical discharge to melt the end of the wire. Techniques for this are described in copending US patent application Serial No. 07/963,346, filed October 19, 1992, which is incorporated herein by reference above.

Figure 10 shows the wire 126 notched (or nicked) to leave wire 120 disposed on surface 122 of pad 106. The wire bond head 124 is retracted upwardly as indicated by arrow 136. The wire bond head 124 has a mechanism to grip and release wire 126 so that wire 126 can be tensioned against the shear blade to sever the wire.

After the wire bonding process is completed, a casting mold 140 as shown in Figure 11 is disposed on surface 142 of substrate 60. The mold is a tubular member of any cross-sectional shape, such as circular and polygonal. The mold is preferably made of metal or organic materials. The length of the mold is preferably the height 144 of the wires 120. A controlled volume of liquid elastomer 146 is disposed into the casting 140 mold and allowed to settle out (flow between the wires until the surface is level) before curing as shown in Figure 13. Once the elastomer has cured, the mold is removed to provide the structure shown in Figure 5 except for cavities 112. The cured elastomer is represented by reference numeral 44. A mold enclosing the wires 120 can be used so that the liquid elastomer can be injection molded to encase the wires 120.

The top surface of the composite polymer/wire block can be mechanically planarized to provide a uniform wire height and smooth polymer surface. A moly mask with holes located over the ends of the wire contacts is used to selectively ablate (or reactive ion etch) a cup shaped recess in the top surface of the polymer around each of the wires. The probe contacts can be reworked by repeating the last two process steps

A high compliance, high thermal stability siloxane elastomer material is preferable for this application. The compliance of the cured elastomer is selected for the probe application. Where solder mounds are probed a more rigid elastomeric is used so that the probe tips are pushed into the solder mounds where a gold coated aluminum pad is being probed a more compliant elastomeric material is used to permit the wires to flex under pressure so that the probe ends in contact with the pad will move to wipe over the pad so that good electrical contact is made therewith. The high temperature siloxane material is cast or injected and cured similar to other elastomeric materials. To minimize the shrinkage, the

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elastomer is preferably cured at lower temperature ($T \leq 60°$) followed by complete cure at higher temperatures ($T \geq 80°$).

Among the many commercially available elastomers, such as ECCOSIL and SYLGARD, the use of polydimethylsiloxane based rubbers best satisfy both the material and processing requirements. However, the thermal stability of such elastomers is limited at temperatures below 200°C and significant outgassing is observed above 100°C. We have found that the thermal stability can be significantly enhanced by the incorporation of 25 wt % or more diphenylsiloxane. Further, enhancement in the thermal stability has been demonstrated by increasing the molecular weight of the resins (oligomers) or minimizing the cross-link junction. The outgassing of the elastomers can be minimized at temperatures below 300°C by first using a thermally transient catalyst in the resin synthesis and secondly subjecting the resin to a thin film distillation to remove low molecular weight side-products. For our experiments, we have found that 25 wt % diphenylsiloxane is optimal, balancing the desired thermal stability with the increased viscosity associated with diphenylsiloxane incorporation. The optimum number average molecular weight of the resin for maximum thermal stability was found to be between 18,000 and 35,000 g/mol. Higher molecular weights were difficult to cure and too viscous, once filled, to process. Network formation was achieved by a standard hydrosilylation polymerization using a hindered platinum catalyst in a reactive silicon oil carrier.

In Figure 10 when bond head 124 bonds the wire 126 to the surface 122 of pad 106 there is formed a flattened spherical end shown as 104 in Figure 6.

The high density test probe provides a means for testing high density and high performance integrated circuits in wafer form or as discrete chips. The probe contacts can be designed for high performance functional testing or high temperature burn-in applications. The probe contacts can also be reworked several

times by resurfacing the rigid polymer material that encases the wires exposing the ends of the contacts.

The high density probe contacts described in this disclosure are designed to be used for testing semiconductor devices in either wafer form or as discrete chips. The high density probe uses metal wires that are bonded to a rigid substrate. The wires are imbedded in a rigid polymer that has a cup shaped recess around each to the wire ends. The cup shaped recess 112 shown in Figure 5 provides a positive self-aligning function for chips with solder ball contacts. A plurality of probe heads 40 can be mounted onto a space transformation substrate 60 so that a plurality of chips can be probed an burned-in simultaneously.

An alternate embodiment of this invention would include straight wires instead of angled wires. Another alternate embodiment could use a suspended alignment mask for aligning the chip to the wire contacts instead of the cup shaped recesses in the top surface of the rigid polymer. The suspended alignment mask is made by ablating holes in a thin sheet of polyimide using an excimer laser and a metal mask with the correct hole pattern. Another alternate embodiment of this design would include a interposer probe assembly that could be made separately from the test substrate as described in US patent application, Serial No. 07/963,364, incorporated by reference herein above. This design could be fabricated by using a copper substrate that would be etched away after the probe assembly is completed and the polymer is cured. This approach could be further modified by using an adhesion de-promoter on the wires to allow them to slide freely (along the axis of the wires) in the polymer material.

Figure 14 shows an alternate embodiment of probe tip 40 of Figures 2 and 3. As described herein above, probe tip 40 is fabricated to be originally fixed to the surface of a first level space transformer 54. Each wire 120 is wire bonded directly to a pad 106 on substrate 60, so that the probe assembly 40 is rigidly fixed

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to the substrate 60. The embodiment of Figure 14, the probe head assembly 40 can be fabricated via a discrete stand alone element. This can be fabricated following the process of US patent application Serial No. 07/963,348, filed October 19, 1992, which has been incorporated herein by reference above. Following this fabrication process as described herein above, wires 42 of Figure 14 are wire bonded to a surface. Rather than being wire bonded directly to a pad on a space transformation substrate, wire 42 is wire bonded to a sacrificial substrate as described in the application incorporated herein. The sacrificial substrate is removed to leave the structure of Figure 14. At ends 102 of wires 44 there is a flattened ball 104 caused by the wire bond operation. In a preferred embodiment the sacrificial substrate to which the wires are bonded have an array of pits which result in a protrusion 150 which can have any predetermined shape such as a hemisphere or a pyramid. Protrusion 150 provides a raised contact for providing good electrical connection to a contact location against which it is pressed. The clamp assembly 80 of Figures 2 and 3 can be modified so that probe tip assembly 40 can be pressed towards surface 58 of substrate 60 so that ends 104 of Figure 14 can be pressed against contact locations such as 106 of Figure 5 on substrate 60. Protuberances 104 are aligned to pads 100 on surface 58 of Figure 5 in a manner similar to how the conductor ends 86 and 88 of the connector in Figure 4 are aligned to pads 75 and 64 respectively.

As shown in the process of Figures 7 to 9, wire 126 is ball bonded to pad 106 on substrate 60. An alternative process is to start with a substrate 160 as shown in Figure 15 having contact locations 162 having an electrically conductive material 164 disposed on surface 166 of contact location 162. Electrically conductive material 164 can be solder. A bond lead such as 124 of Figure 7 can be used to dispose end 168 of wire 170 against solder mound 164 which can be heated to melting. End 168 of wire 170 is pressed into the molten solder mound to form wire 172 embedded into a solidified solder mound 174. Using this process a structure similar to that of Figure 5 can be fabricated.

Figure 16 shows another alternative embodiment of a method to fabricate the structure of Figure 5.

Numerals common between Figures 15 and 16 represent the same thing. End 180 elongated electrical conductor 182 is held against top surface 163 of pad 162 on substrate 160. A beam of light 184 from laser 186 is directed at end 180 of elongated conductor 182 at the location of contact with surface 163 of pad 162. The end 180 is laser welded to surface 163 to form protuberance 186.

In summary, the present invention is directed to high density test probe for testing high density and high performance integrated circuits in wafer form or as discrete chips. The probe contacts are designed for high performance functional testing and for high temperature burn in applications. The probe is formed from an elastomeric probe tip having a highly dense array of elongated electrical conductors embedded in an elastomeric material which is in electrical contact with a space transformer.

While the present invention has been described with respect to preferred embodiments, numerous modifications, changes and improvements will occur to those skilled in the art without departing from the spirit and scope of the invention.

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